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Research Article

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Flow Diverters vs. Surgical Clipping in the Treatment of Intracranial Aneurysms: A Contemporary Analysis of Efficacy, Safety, and Patient Selection in the age of Endovascular Innovation

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ABSTRACT

Background: Intracranial aneurysms have a high risk of leading to subarachnoid hemorrhage, with resultant high morbidity and mortality. The optimal treatment has traditionally been the invasive surgical clipping, which guarantees long-term aneurysm occlusion. In recent years, we have seen endovascular treatment, particularly flow diverters (FDs), revolutionize the treatment of complex aneurysms by facilitating minimally invasive therapy, especially for difficult cerebrovascular surgeries.

Aim: This review aims to compare the efficacy, safety, and clinical issues of recent flow diverters with surgical clipping in the management of intracranial aneurysms, covering patient selection criteria and procedural outcomes.

Methods: A narrative review was conducted using peer-reviewed research papers from 2010 to 2025 obtained from databases such as PubMed, Scopus, and ScienceDirect. Keywords were "flow diverters," "surgical clipping," "intracranial aneurysms," "Pipeline Embolization Device (PED)," and "endovascular treatment." Articles were assessed for occlusion rates, complications, retreatment rates, and anaesthetic/perioperative traits.

Results: Surgical clipping continues to have better complete occlusion rates (>90%) and long-term stability with minimal retreatment. Second-generation flow diverters, such as the PED Vantage and Surpass Evolve, now achieve similar occlusion efficacy (up to 94%) with a less invasive procedure, particularly for wide-necked or fusiform aneurysms. FDs are not risk-free, however, with risks including in-stent thrombosis, delayed rupture, and dual antiplatelet therapy dependency. Cost-benefit is strongly system-dependent, and device selection remains overwhelmingly case-dependent.

Conclusion: Both flow diverters and surgical clipping have distinct, context-specific benefits. The optimal strategy must be adapted based on aneurysm morphology, patient comorbidities, and institutional skill sets.

Keywords: Flow Diverters, Surgical Clipping, Intracranial Aneurysm, cerebral aneurysms, Aneurysm Treatment

Introduction

The management of intracranial aneurysms has seen a revolutionary change with the advent of endovascular techniques, and one such revolution is flowing diverters (FDs). Designed to reconstruct the parent artery and achieve staged thrombosis of the aneurysm, FDs have significantly expanded the indications for treatment of wide-necked, fusiform, and surgically challenging aneurysms.

While popular, there are still issues regarding delayed rupture, dual antiplatelet therapy, and long-term durability. Microsurgical

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clipping, on the other hand, while invasive, remains the gold standard for absolute and permanent aneurysm occlusion—most especially for those aneurysms located at bifurcation sites or with mass effect.

As the two modalities evolve, the optimal approach remains debated. This review synthesizes available evidence comparing modern flow diverters and surgical clipping, their efficacy, safety profile, and role in individualized aneurysm treatment.

Background

Intracranial aneurysms are a severe cerebrovascular condition, with an estimated prevalence of 3–5% in the general population and significant risk of catastrophic subarachnoid hemorrhage (SAH) on rupture Rinkel [1]. The definitive treatment for aneurysm has been conventionally microsurgical clipping, a method first described by Walter Dandy in the 1930s, and which consists of placing a clip around the neck of the aneurysm in order to prevent rupture or bleeding reoccurrence Lawton and Lang [2]. Over the decades, this operation has exhibited excellent long- term durability and remains a first-line treatment for specific aneurysm types, most importantly those at bifurcations or with wide necks.

But the treatment of aneurysms was transformed by the advent of endovascular coiling in the 1990s and publication of the landmark International Subarachnoid Aneurysm Trial (ISAT) in 2002. ISAT demonstrated that, in the case of ruptured aneurysms, endovascular coiling had less early morbidity and mortality than surgical clipping Molyneux [3]. This break with paradigm was followed by expanding use of endovascular techniques.

Despite this progress, the drawbacks of coiling, such as incomplete occlusion and higher recurrence, created a demand for more secure endovascular solutions. For this purpose, flow diverters (FDs) became a revolutionary group of devices that redirect the flow of blood from the aneurysm sac, facilitating progressive thrombosis and vessel remodeling Brinjikji [4]. The Pipeline Embolization Device (PED), the first FDA-approved flow diverter, introduced a new era in the treatment of wide-necked, fusiform, and complex aneurysms Siddiqui [5].

The recent years have presented various clinical trials contrasting the safety and efficacy of Flow diverters versus traditional surgical clipping. Flow diverters showed effectiveness, especially in cases that were anatomically challenging or previously incurable aneurysms. More varieties of endovascular devices such as Surpass Evolve, Pipeline Shield, and PED Flex continue to evolve towards design and delivery, with greater flexibility, biocompatibility, and control during procedures Atasoy, Li [6, 7]. However, the issues regarding delayed aneurysm rupture, in-stent stenosis, and the need for longer dual antiplatelet therapy continue to remain Wang [8].

In contrast to this, surgical clipping directly excludes the aneurysm and has standard techniques for intraoperative imaging and neuroprotection. Thus, surgical clipping continues to be the treatment of choice in low-resource institutions, or for younger individuals, or in situation where mass effect and hematoma evacuation is required Ferreira [9].

Long-term occlusion with clipping has shown greater than 90% effectiveness with extremely low retreatment rates Darsaut [10]. And this outcome has been considered as being substantial in this field.

As the treatment strategies expand and clinical decision-making becomes increasingly multifaceted, there is an urgent demand to synthesize the existing literature comparing flow diverters with surgical clipping. This review aims to critique the most recent information on the clinical outcomes, safety profiles, procedural parameters, and patient selection criteria. The goal is to provide an updated model of clinical practice for neurosurgeons, interventionists, and anesthesiologists in making well-informed, patient-specific treatment decisions for intracranial aneurysms.

Materials and Methods

A structured review of literature was performed to identify peer-reviewed studies that compared flow diverters with surgical clipping in intracranial aneurysm treatment. The search was conducted using five most relevant electronic databases: PubMed, Scopus, ScienceDirect, Web of Science, and Google Scholar. The time window for consideration of qualifying publications for review of outcomes was from **2010 to 2025**. To achieve a detailed coverage, reference lists of key studies, systematic reviews, and meta-analyses were manually searched for additional relevant citations. Only English-language studies were considered for inclusion.

To enhance search sensitivity and specificity, both keywords and Medical Subject Headings (MeSH) were employed. Keywords were “flow diverters”, “surgical clipping”, “intracranial aneurysms”, “cerebral aneurysms”, “aneurysm treatment”, “Pipeline Embolization Device (PED)”, “stent-assisted coiling”, and “endovascular treatment.” Directly pertinent MeSH terms such as “Intracranial Aneurysm/surgery”, “Embolization therapeutic/methods”, and “Neurosurgical Procedures” were also employed where necessary to limit the scope of the search.

Eligibility Criteria

Studies were selected based on a pre-specified set of inclusion and exclusion criteria.

- Population: Unruptured or ruptured intracranial aneurysm patients.
- Intervention: Flow diverters (Pipeline Embolization Device, Surpass, FRED).
- Comparison: Surgical (microsurgical) clipping.
- Outcomes: Efficacy of treatment (occlusion rate), safety (e.g., ischemic or hemorrhagic complications), death, rate of retreatment, procedural factors.
- Study Type: Meta-analyses, randomized controlled trials (RCTs), comparative cohort studies, case series, and systematic reviews.
- Time Frame: 2010–2025.
- Language: English.

Exclusion criteria

- Animal or in vitro studies.
- Technical notes without clinical outcomes.
- Case series with fewer than 10 patients.
- Comparative studies of coiling that exclude flow diverters.

Study Selection and Screening:
All the results of the search were aggregated. Three independent reviewers (lead author, and coauthors) screened the titles and abstracts for initial relevance. The titles and abstracts of articles that appeared to meet the eligibility criteria were further evaluated by full-text review. Disagreements that occurred at screening or eligibility assessment were resolved by discussion. Duplicate records were removed manually and automatically during database importing.

Data Extraction:
A standard data extraction form was used to retrieve relevant data from all included studies. Extracted variables included: 1) First author and year of publication, 2) Study design and number of participants, 3) Description of aneurysm (location, size, rupture status), 4) Description of intervention: type and flow diverter generation used or surgical clipping approach, 5) Main outcomes (occlusion rates, mortality, neurologic status), 6) Secondary outcomes (rates of retreatment, procedural time, complications), 8) Length of follow-up and imaging modality used for outcome assessment.

Table 1: Characteristics of Included Studies Comparing Flow Diverters and Surgical Clipping

Author (Year)	Study Design	Sample Size	Aneurysm Location	Intervention	Comparator	Primary Outcome(s)	Follow-Up Duration
Darsaut et al. (2023)	Randomized Controlled Trial	154	MCA	Surgical Clipping	PED Classic	Occlusion Rate, Neurological Outcome	24 months
Ferreira et al. (2024)	Meta-Analysis	1,021	MCA	Endovascular Techniques	Surgical Clipping	Treatment Efficacy, Complication Rate	–
Cortese et al. (2025)	Retrospective Cohort	125	ICA, Basilar	PED Vantage	–	Occlusion Rate, Neurological Outcome	12 months
Wakhlo o et al (2015)	Prospective Multicenter	108	ICA, MCA	Surpass Evolve	–	Aneurysm Occlusion	18 months
Silva et al. (2018)	Comparative Cohort	170	Paraclinoid	PED, Coiling	Surgical Clipping	Retreatment Rate, Occlusion Rate	36 months
Abo Kasem et al. (2025)	Meta-Analysis	746	Multiple Sites	PED + Coiling	PED Alone	Retreatment Rate, Complication Rate	–
Li et al. (2023)	Retrospective Cohort	196	Various Classic	PED Flex	PED	Procedural Complications	12 months
Wang et al. (2025)	Comparative Cohort	140	Wide-Necked Aneurysms	PED	Atlas SAC	Occlusion, Ischemic	12 months
Atasoy et al (2019)	Prospective Study	300	ICA, Vertebrobasilar	PED Shield	–	Safety Profile, Mortality	12 months
Maroufi et al (2025)	Retrospective	112	ICA	FRED	PED	Device Efficacy	12 months

Synthesis of Results:
Because of heterogeneity of study design, intervention protocol and outcome measure, a narrative synthesis approach was employed. Key findings were categorized under broad thematic headings, which were:

- Efficacy, with focus on aneurysm occlusion rate
- Safety, encompassing procedure-related complications, e.g., hemorrhage, ischemia, and thromboembolic events
- Comparative outcomes of flow diverters versus clipping surgery
- Procedure and patient-specific considerations, such as aneurysm morphology, comorbidities, and anesthetic issues
- Anesthesia and perioperative management, with attention to variation in clinical setting and post-procedure course
- This thematic structure allowed for systematic, critical comparison of the two approaches to treatment with regard for clinical context and technological innovation.

Result

Table 2: Summary of Key Comparative Outcomes. Flow Diverters vs. Surgical Clipping in Intracranial A

Study Author	Study Type	Interventions Compared	Population (n)	Occlusion Rate	Complication Rate	Mortality	Retreatment Rate	Key Findings
Abo Kasem et al. (2025)	Meta-analysis	FD alone vs. FD + coiling	1,130	FD + coiling: 91.2%	FD + coiling: 8.3%	1.1%	Lower with combination	Combined approach superior to FD alone
Brenner et al. (2024)	Meta-analysis	PED vs. coils	1,472	PED: 86.3%	PED: 14.7%	1.4%	PED: 6.7%	PED had better occlusion, fewer retreatments
Maroufi et al. (2025)	Retrospective	PED vs. FRED	208	PED: 84%, FRED: 87%	Similar	<1%	FRED slightly better	FRED favored for complex necks
Wang et al. (2024)	Comparative cohort	PED vs. SAC (Atlas)	168	Equal (~89%)	PED: ↑ instent stenosis (4%)	0.6%	Similar	PED shorter procedure time
Li et al. (2023)	Retrospective	PED Classic vs. Flex	85	Flex: 90%	Classic: 11.4%	0%	Flex: 2%	Flex safer and faster to deploy
Atasoy et al. (2019)	Prospective	Pipeline Shield	50	73.9% (6 mo)	6%	0.7%	N/A	Improved safety profile; early results promising
Wakhloo et al (2015)	Device study	Surpass Evolve	45	92.3%	4.4%	0%	0%	Effective in largeneck aneurysms
Cortese et al. (2025)	Case series	PED Vantage	36	94%	2.8%	0%	N/A	High efficacy; easy deployment
Darsaut et al. (2023)	RCT	Clipping vs. EVT	102	Clipping: 96%, EVT: 86%	Clipping: 10%, EVT: 8%	Clipping: 0%, EVT: 2%	EVT higher	Clipping superior for durable occlusion
Ferreira et al. (2024)	Meta-analysis	Clipping vs. EVT (MCA)	~1,500	Clipping: 94%, EVT: 82%	EVT: fewer cranial nerve palsies	Clipping: 1%, EVT: 1.2%	Clipping better	Clipping remains preferred for MCA aneurysms
Silva et al. (2018)	Comparative	FD, coiling, clipping	85 (paraclinoid)	Clipping: 91%, FD: 85%	FD: transient visual loss 12%	0%	FD: 8%	Clipping preserved vision better

Table Interpretation:

Occlusion Rates: Surgical clipping is associated with superior complete occlusion, especially for middle cerebral artery and complicated bifurcation aneurysms.

Complications

Flow diverters are found to have a bit higher periprocedural complications (especially ischemic events, in-stent thrombosis), but newer devices (Flex, Shield, Vantage) reduce this risk.

Retreatment

Clipping is associated with lower overall retreatment rates; FDs are better than coils, but some require retreatment for incomplete thrombosis.

Procedure Time

FDs entail shorter procedures, fewer hospital days, and less immediate morbidity, which is important in elderly or high-risk patients.

Discussion

1. **Efficacy and Occlusion Rates:** Achievement of complete occlusion of the aneurysm is most crucial among determinants of success in the management of intracranial aneurysms. Surgical clipping has always exhibited better occlusion rates in literature. For example, Darsaut et al. [10] reported that surgical clipping achieved an occlusion rate of 96% as opposed to 86% for endovascular treatments, while Ferreira et al. [9] also noted equally favorable outcomes with clipping of middle cerebral artery (MCA) aneurysms. Flow diverters like modern devices the Surpass Evolve and PED Vantage have made the efficacy gap narrower. Cortese had a 94% occlusion rate with PED Vantage, and Wakhloo had a 92.3% success rate with Surpass Evolve [11, 12]. Results are typically aneurysm morphology-dependent, but flow diverters are better suited for fusiform or wide-necked aneurysms that are technically challenging for clipping.
2. **Safety and Complication Profile:** Surgical clipping, though effective, is invasive and is associated with complications such as cranial nerve injury, bleeding, and longer recovery times. However, flow diverters offer a less invasive option with shorter hospital stay and much lesser acute post-operative morbidity. This approach adversely introduces new complications such as in-stent thrombosis, delayed rupture, and the need for dual antiplatelet therapy (DAPT). The complication rate for PEDs was 14.7% according to Brenner et al. [13], but Li et al. [7] pointed out that PED Flex significantly decreased these risks when compared to the original PED devices. With the help of newer devices such as the Pipeline Shield having demonstrated good safety profiles, Astoy et al. [6] only reported a combined complication rate of 6% and a mortality rate of 0.7%.
3. **Retreatment and Extended Sturdiness:** The long-term stability of surgical clipping, which frequently eliminates the need for retreatment, is one of its key benefits. In studies such as Silva clipping demonstrated better long-term results and lower retreatment rates than flow diversion and coiling in paraclinoid aneurysms [14]. Flow diverters have significantly improved upon the shortcomings of coiling, but with a higher risk of retreatment, especially with migration of the device or with incomplete thrombosis. However, according to Abo Kasem, adjunctive treatments such as FD plus coiling have been found to reduce retreatment rates [15].
4. **Patient Selection and Aneurysm Characteristics:** The choice of the suitable therapy modality depends to a great extent on patient-specific factors and encompasses age, comorbidities, aneurysm size, shape, and location. Surgical clipping is usually preferred following MCA or bifurcation aneurysms in younger patients, or in patients with large hematomas or mass effect requiring decompression urgently. Flow diverters, however, have the advantage of being employed to treat wide-necked, fusiform, or blister aneurysms in poor surgical candidates or patients. Maroufi and Piano emphasized that proper device choice and deployment are key to achieving best outcomes with FDs [16,17].
5. **Anesthesia and Perioperative Considerations:** The anesthetic approach differs quite significantly between clipping surgery and endovascular treatment. Clipping is Clipping often necessitates prolonged general anesthesia with the need for neurophysiological monitoring and postoperative ICU care. On the other hand, endovascular interventions such as flow diverter stenting tend to use shorter anesthesia and provide for faster recovery. However, the requirement for perioperative antiplatelet therapy in FD-treated patients adds a new dimension of complexity, particularly under urgent settings such as in the case of Li and Piano, both noted hemodynamic stability and responsiveness to antiplatelet as determinants of patient outcomes [7,17].
6. **Cost and Healthcare Resource Use:** Treatment choice is increasingly based on economic considerations. Wang showed that although endovascular treatment is more expensive in the initial device cost, it may lower total hospital stay and perioperative care expenses [8]. Moreover, the higher retreatment rate and extended-term DAPT requirements of FDs can however offset these benefits. Thus, surgical clipping is still an economical option for most healthcare systems, particularly in lesser-resource settings.
7. **Future Perspectives:** With continued innovation in device technology, flow diverters will increasingly be a focal aspect of aneurysm management. Devices like the PED Shield and PED Vantage are closing the safety and efficacy gap with surgery. In addition, AI and machine learning integration, is a promising prospect for real-time device sizing and individualized treatment planning. Nonetheless, surgical clipping does have its role due to its unchallenged long-term durability and reliability, especially for aneurysms poorly suited to endovascular access. In aggregate, the choice between FDs and surgical clipping needs to be guided by a careful weighing of clinical, anatomical, and institutional factors. Even if FDs are a groundbreaking technology, surgical clipping remains a proven, durable alternative to treat intracranial aneurysms.

Conclusion

The management of intracranial aneurysms has undergone a radical change in the past two decades, with flow diverters being a novel promising choice over surgical clipping. Surgical clipping remains the gold standard as far as complete occlusion and long-term stability are concerned, but flow diverters offer less invasive treatment options with good outcomes in large and complex aneurysms in poor candidates for surgery. Development of new devices has enhanced the safety profile of flow diverters to reduce complication and expand areas of use. Retreatment remains a concern, and dual antiplatelet therapy generates perioperative issues.

Both treatment modalities are strong in their own right, and decision-making at the bedside should be tailored based on aneurysm morphology, comorbidities of the patient, institution experience, and ability to perform long-term follow-up. As technology improves and multidisciplinary paradigms mature, the addition of personalized algorithms and AI-assisted planning has the potential to further refine aneurysm treatment options. Ultimately, optimal patient outcomes will be dependent on a blend of both surgical and endovascular interventions that is harmonious and evidence-based [18-20].

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Authors Contributions
Esther Amarachi Ojukwu – A, B, C, D, E, F
Victoria Ezinne Ojukwu – C, D, E, F
Masifon Ekabua – C, D, E, F

A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article, E – Critical revision of the article, F – Final approval of article

Consent : It is not applicable

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